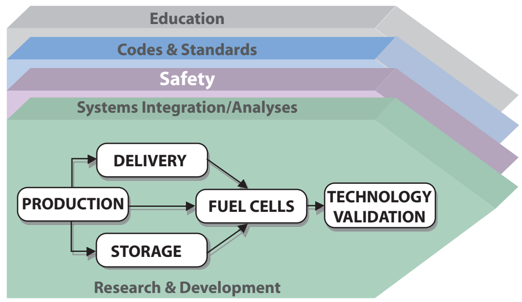
3.7. Hydrogen Safety



Safe practices in the production, storage, distribution and use of hydrogen are essential components in a hydrogen economy. The Safety Program element delineates the steps that the Hydrogen, Fuel Cells & Infrastructure Technologies Program is taking to ensure that its projects are performed in a safe manner and that lessons learned within the Program are used to promote safety throughout the hydrogen economy.

Like other fuels in use today, hydrogen can be used safely with appropriate handling and systems design. Its risk level as a fuel at atmospheric pressure is similar to that of fuels such as natural gas and liquid petroleum gas. Because of the smaller size of the molecule and the greater buoyancy of the gas, hydrogen requires storage, handling and use techniques that are different than those traditionally employed. The aim of this Program element is to ensure the safe use of hydrogen, and to understand, communicate and provide training on the safety hazards related to the use of hydrogen as a fuel. The Program element will also maintain a comprehensive database on hydrogen and hydrogen safety.

3.7.1 Goal and Objectives

Goal

Develop and implement the practices and procedures that will ensure safety in the operation, handling and use of hydrogen and hydrogen systems for all DOE projects and to utilize these practices and lessons learned to promote the safe use of hydrogen throughout the emerging hydrogen economy.

Objectives

- Starting in 2004, integrate safety procedures into new DOE projects to ensure that they all incorporate hydrogen safety requirements.
- By 2005, develop a comprehensive safety plan in collaboration with industry that establishes Program safety policy and guidelines. The Safety Review Panel, formed in FY 2004, will continue to provide expertise and guidance to the DOE, and will assist with identifying areas of additional research.
- By 2007, publish a handbook of "Best Management Practices for Safety." The Handbook will be a "living" document that will provide guidance for ensuring safety for DOE hydrogen projects, while serving as a model for all hydrogen projects and for commercialization.
- Develop supporting research and development program to provide critical hydrogen behavior data and hydrogen sensor and leak detection technologies. This data will support the establishment of setback distances in building codes.
- Promote widespread sharing of safety-related information, procedures and lessons learned to first responders, jurisdictional authorities and other stakeholders.

3.7.2 Approach

The Safety Program element focuses on the following activities:

- Conduct safety reviews of current and future projects, including practices and procedures.
- Develop and provide a database on safety, including component reliability, materials, sensors and hydrogen releases.
- Develop a safety training program for emergency responders and authorities having jurisdiction.
- Develop safety-related components such as sensors and coating materials.
- Investigate system approaches for integrated safety in design.
- Determine whether the current safety classification accurately reflects the behavior of hydrogen.

Safety is always an important focus of DOE efforts, but it must receive special emphasis during these critical early stages of the envisioned hydrogen transition. The successful development of hydrogen as an energy carrier will require an exceptional safety record. The risks and consequences of any accident must be minimized or completely mitigated. Safety practices and procedures established now will carry into the future, and thus offer long-term benefits as well.

Comprehensive safety management is a necessary step in the safe operation, handling and use of hydrogen and related hydrogen systems. Safety management will ensure continued safe operations throughout the emerging hydrogen transition, provide experimental data for hydrogen safety scenarios, and work to improve the public's perception of hydrogen.

Safety Management

Safety management is implemented through the document, "Guidance for Safety Aspects of Proposed Hydrogen Projects" available on the DOE Web site (http://www.eere.energy.gov/hydrogenandfuelcells/). This document details safety plans that must be submitted for each DOE-funded project. Such systematic application of safety assessment methodologies reduces the likelihood that a potential risk may be overlooked, and allows a consistent measure of safety across all DOE-supported hydrogen projects. The safety plans of the learning demonstrations and the lessons learned under the Technology Validation Program element (see section 3.5) will play an important role in the development of safe practices that are essential for future commercialization.

Hydrogen Safety Review Panel

DOE formed an independent Hydrogen Safety Review Panel in FY 2004 to provide expert guidance on safety and hazard mitigation in DOE activities, programs and projects. Its objectives are to help DOE identify safety concerns; determine current status of regulations, policies, codes, standards and guidelines; and provide a national platform to discuss critical hydrogen safety issues. The Panel consists of a diverse set of experts representing a breadth of industries and organizations including insurance, fuel providers, aerospace, fire safety, engineering and others, providing well over one hundred years of collective safety experience. The Panel provides an independent assessment of safety plans, makes recommendations, and proposes alternatives and/or needs for additional analysis or review, as appropriate. Experience gained through the safety panel and learning demonstrations will form the basis for a "Handbook of Best Management Practices" to be published in 2007.

Safety Data

Data and its proper classification present a number of challenges confronting hydrogen use. For example, the way hydrogen is classified throughout the world is inconsistent. Some countries, including the U.S., currently classify hydrogen as a hazardous material, and not as a fuel. This classification directly impacts issues like storage and transportation through the regulations that consequently apply. One activity of the Program element will be to determine whether the current hazardous material classification accurately reflects the actual risk of hydrogen systems. The desired outcome of these activities is that hydrogen will be classified as a fuel for transport and handling, comparable to today's traditional fuels.

Other kinds of data needs also exist because hydrogen has been used primarily as a feedstock chemical (aside from aerospace applications, which are generally non-commercial). In addition, safety-related information, often corresponding to company-specific chemical processes and handling procedures, has been treated as proprietary. The widespread availability and communication of safety-related information will be crucial to ensure safe operation of future hydrogen fuel systems and thus are emphasized.

Although safety-by-design and passive mitigation systems are preferred, it will still be necessary to develop technologies to detect hydrogen releases or other system failures. This Program element will develop hydrogen sensors with the appropriate response time, sensitivity and accuracy for use in safety applications to reduce risk and help establish public confidence. For example, coatings that change color upon exposure to hydrogen can provide immediate visual evidence of a leak, while other coatings can be used to rapidly catalyze any small amounts of hydrogen that do escape.

Finally, the Safety Program element coordinates with the Education (deferred) and Codes and Standards Program elements to develop training materials and practices to foster the safety of projects and technologies. A thorough approach to safety will enable risks to be measured and mitigated, and assist in establishing affordable insurability.

3.7.3 Status

Before publishing this RD&D plan, DOE addressed hydrogen safety as a contractual requirement between funded parties, relying on existing protocols and practices by the national laboratories, universities and industry to review and enforce safety in R&D projects. Larger demonstration projects were required to provide third party safety reviews after an award, but before hardware testing. Some aspects of these safety evaluations included the appropriate use of applicable model building codes and equipment standards, the use of hydrogen sensors to help detect hydrogen leaks and modeling and testing of potential leak/accident scenarios.

Project safety is now pursued in large part through the efforts of the Hydrogen Safety Review panel. A principal activity of the Panel is to assess DOE hydrogen projects from a safety perspective, and make recommendations for improvement, where appropriate. An individual project assessment involves review of the project's safety plan, at a minimum, and may include a site visit by one or more Panel members.

Figure 3.7.1 Air Products Hydrogen Fueling Station in Las Vegas, Nevada

The first site visit of the panel took place in March 2004 at the Las Vegas Hydrogen Energy Station in Nevada, shown in Figure 3.7.1. Through the end of FY04, the Panel will have completed five more site visit reviews and scheduled additional reviews for FY05. The Hydrogen, Fuel Cells & Infrastructure Technologies Program will continue to select a portfolio of projects for safety review. Review teams, consisting of Panel members, work with principal investigators and their teams through scheduled site visits.

Project teams have also used access to panel expertise to tap the body of knowledge that already exists for dealing with hydrogen and hydrogen-related systems.

Another major issue on which the Safety Program element focuses is the information, materials and facilities for training and educating various audiences that are critical to the hydrogen transition. Industry and aerospace have a long history of safe hydrogen use, but the introduction of hydrogen as a commercial fuel in the hands of the general public introduces a host of new safety issues that must be addressed prior to the hydrogen economy's implementation. Accidents or other system failures within the established fuel infrastructure of commonly used fuels can and do occur. For any fuel, a suitably trained emergency response force is an essential element to minimize safety-related incidents. Training of first responders is of particular importance to the successful implementation of the hydrogen economy, especially in its nascent stages, as a loss in public confidence related to its safety could derail the entire transition strategy.

Figure 3.7.2 Emergency Responder Training at the HAMMER site in Richland, Washington.

The Volpentest **HA**zardous **M**aterials **M**anagement and **E**mergency **R**esponse (HAMMER) Training and Education Center is the result of a $29.9 million federal investment completed in 1997 at the Hanford Nuclear Reservation in Washington state. HAMMER was established to provide critical training in fire operations, nuclear materials handling and transport, occupational safety and health, and other areas relevant to the Hanford mission (see Figure 3.7.2). DOE plans to establish a national hydrogen safety training facility by expanding current training capabilities at HAMMER, beginning in FY 2005.

3.7.4 Challenges

Developing a comprehensive safety plan is challenging, partly because the database of safety information on many hydrogen components and systems is largely limited to industrial practice. Scientific and technical knowledge may also be limited because each company that produces and uses large quantities of hydrogen has established training practices that must be followed for liability reasons, and these practices may not be necessarily public information. Companies that use these practices comply with federal regulations, which are accepted by insurance providers. Any new information may not be published, perhaps due to company policy or because is may be considered proprietary.

The tendency for hydrogen to leak presents a challenge to its storage and delivery. As a flammable gas, leakage creates a safety hazard. The Safety Program element works with other Program elements to eliminate leakage and to develop design principles and systems that detect and mitigate the effects of hydrogen leakage.

There is a general lack of understanding of hydrogen and hydrogen safety needs among local government officials, fire marshals and the general public. It is common for new endeavors to encounter resistance simply because they are different from the known and accepted. Public opposition to siting of hydrogen refueling stations has occurred in several instances, even preventing operation of the station in some cases. Such public discomfort typically stems from misperceptions and confusion of hydrogen technologies with a "hydrogen bomb" or with the Hindenburg disaster. In other cases, the local regulatory authority may view one or more properties in isolation without considering other properties that could mitigate danger (e.g., hydrogen's tendency to rapidly disperse once released). Failing to consider the "big picture" may lead to over-restrictive policies that preclude implementation.

The general public who uses the published information in many handbooks or training programs may be getting limited or inaccurate information. For example, although hydrogen is listed as a Class B hazard, it is unclear that this classification is based on accurate or reproducible data. There also is no comprehensive handbook containing best management practices for hydrogen safety, to date. Once mandatory reporting is established for safety and reliability, training will be required to adequately educate appropriate government officials. Finally, all the data to be used in assessing the safety of hydrogen systems must meet the needs of insurance providers and other stakeholders. This Program element is working to fill these gaps through R&D, training, and tracking of safety-related incidents and lessons learned.

The technical challenges discussed elsewhere in this RD&D program plan must be overcome and the solutions demonstrated to be reliable, safe and cost-effective. That these solutions are safe must be convincingly communicated to not only crucial enablers of the technology like regulatory authorities, but also the public at large. In the end, a failure in public confidence with regard to the relative safety of hydrogen will render other implementation issues moot. Such challenges can and must be overcome, and documented through consistent, clear and timely communication.

3.7.4.1 Targets

Table 3.7.1 summarizes the technical targets associated with the Safety Program element that addresses sensor R&D.

Table 3.7.1. Targets for Hydrogen Safety Sensor R&D

- **Measurement Range: 0.1%-10%**
- **Operating Temperature: -30 to 80°C**
- **Response Time: under one second**
- **Accuracy: full scale**
- **Gas environment: ambient air, 10%-98% RH range**
- **Lifetime: 5 years**
- **Interference resistant (e.g., hydrocarbons)**

3.7.4.2 Barriers

This section details the barriers that must be overcome to achieve the goal and objectives of the Safety Program element.

A. **Limited Historical Database.** Only a small number of hydrogen technologies, systems and components are in operation. Only limited data is available on the operational and safety aspects of these technologies.

B. **Proprietary Data.** Hydrogen technologies, systems, and components are still in the pre-commercial development phase. Only limited non-proprietary data is available on the operational and safety aspects of these technologies. Sharing safety data is important for hydrogen projects funded under the Program.

C. **Validation of Historical Data.** The historical data used in assessing safety parameters for the production, storage, transport and utilization of hydrogen are several decades old. Validation of this data and an assessment of use may prove useful in the development of a hydrogen infrastructure.

D. Liability Issues. Potential liability issues and lack of insurability are serious concerns that could affect the commercialization of hydrogen technologies.

E. Variation in Standard Practice of Safety Assessments for Components and Energy Systems. Variations in safety practices and lack of standardization across hydrogen technical projects increase the risk of safety related incidents.

F. Safety is Not Always Treated as a Continuing Process. Safety practices will need to be maintained throughout the duration of the project.

G. Expense of Data Collection and Maintenance. Principal Investigators need to pursue the detailed collection and maintenance of all safety data and information regardless of the added expense.

H. Lack of Hydrogen Knowledge by Authorities Having Jurisdiction. Officials given the responsibility of approving the safety of installations of various technologies often have insufficient knowledge of hydrogen and its properties and characteristics to complete the approval.

I. Lack of Hydrogen Training Facilities for Emergency Responders. A suitably-trained emergency response force is an essential element of preventing an accidental hydrogen release from progressing from an incident with little or no damage to one of much greater consequences. The current level of responder experience with hydrogen technologies is lacking, in part because there are no current facilities in the U.S. offering emergency response training specific to hydrogen.

3.7.5 Task Descriptions

Task descriptions are presented in Table 3.7.2.

Table 3.7.2. Technical Task Descriptions

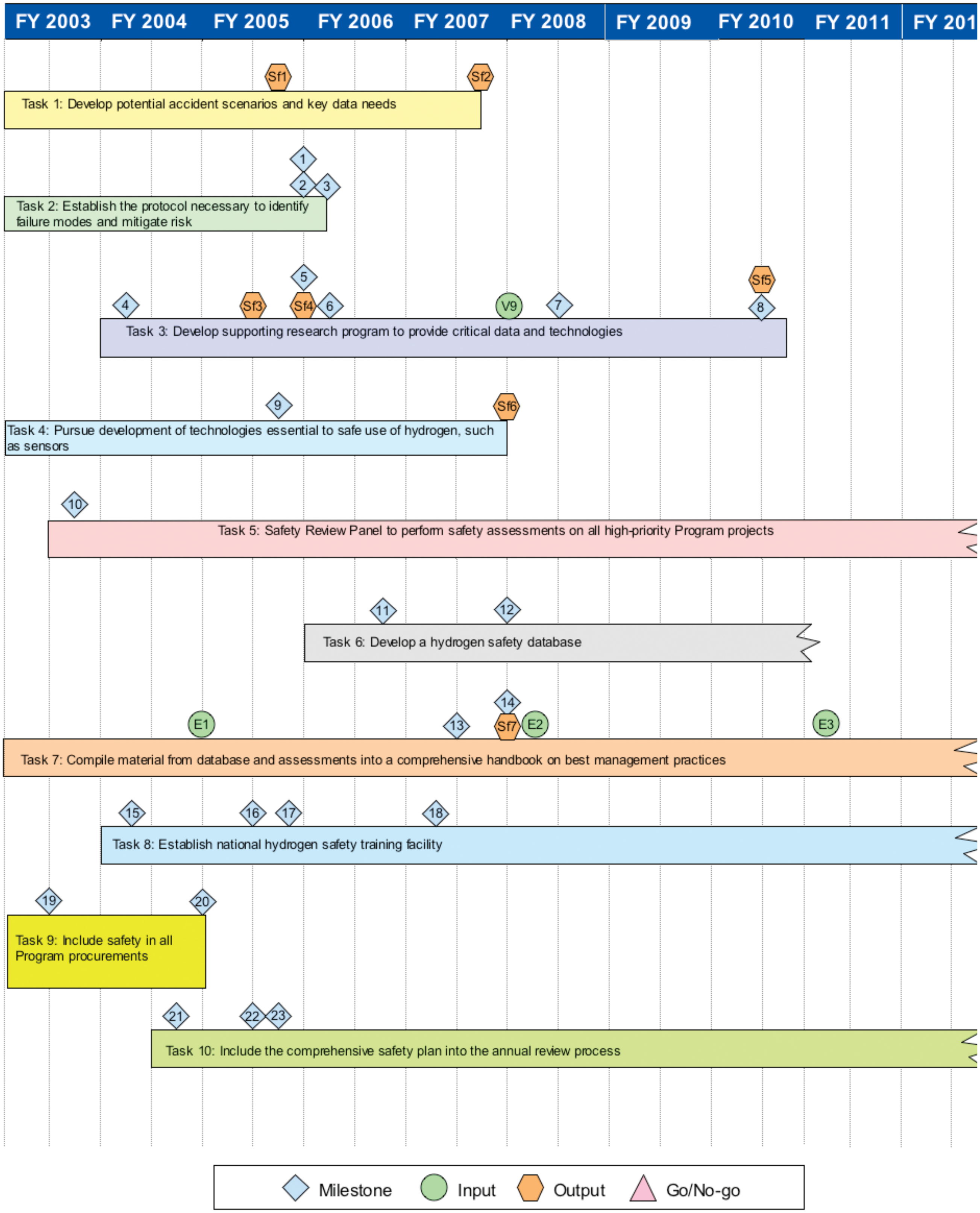
Task	Description	Barriers
1	**Develop potential accident scenarios and key data needs** • Identify what can go wrong. • Develop a system for classifying accident types. • Develop a methodology for estimating accident likelihood. • Develop and release a report of the most common accident scenarios.	A, B, C, G
2	**Establish the protocol necessary to identify failure modes and mitigate risk** • Draft protocol for identifying potential failure modes and risk mitigation. • Work with industry experts to review and revise the protocol. Release consensus protocol to become part of program solicitations.	A, B, C, G
3	**Develop supporting research program to provide critical data and technologies** • A supporting research program will be developed to provide missing data. The literature search performed to identify failure modes will be evaluated to identify the areas where additional research is necessary. • Explore systems approaches and "holistic" design strategies for development of systems that are inherently safer.	A, B, C, E, G
4	**Develop technologies essential to safe use of hydrogen, such as sensors**	D, E

5	**Safety Review Panel to perform safety assessments on Program projects** • Conduct site visits of selected projects. • Review safety plans of Program projects. • Provide input for Best Management Practices Handbook (see Task 7).	A, B, C, D, E, F, G
6	**Develop a hydrogen safety database** • Develop a repository for hydrogen safety data and information. • Compile data and populate database. • Publish database.	A, B, C
7	**Compile material from database and assessments into a comprehensive handbook on best management practices** • Safety Review Panel will prepare draft. • Publish final Best Management Practices Handbook and support the adoption of these practices throughout the hydrogen economy.	A, B, C, D, E, F, G, H, I
8	**Establish national hydrogen safety training facility** • Establish DOE HAMMER site as a central location for safety-related information and training. • Develop a five-year plan.	H, I
9	**Include safety in all Program procurements** • Develop guidelines for all DOE funded projects to include safety planning in all aspects of the project, including safety incident tracking. • Publish guidelines.	E, F, G
10	**Include the comprehensive safety plan into the annual review process** • Establish criteria for Annual Review process. • The Safety Review Panel will incorporate the safety-related comments of the Peer Review Team into its business practices.	F, G

3.7.6 Milestones

Figure 3.7.3 shows the interrelationship of milestones, tasks, supporting inputs from other Program elements and outputs for the Hydrogen Safety Program element for FY 2004 through FY2010. This information is also summarized in Table B.7 in Appendix B.

Figure 3.7.3. Hydrogen Safety R&D Milestone Chart



For chart details see next page.

Milestones

1 Prepare draft failure modes and risk mitigation protocol.
2 Conduct workshop to review draft protocol.
3 Release consensus protocol.
4 Initiate collaboration with NASA, DOT, and other agencies to establish and publish an interagency plan on the cooperation of hydrogen safety R&D.
5 Review existing data and hydrogen classification.
6 Develop design protocol that employs passive system or holistic design techniques.
7 Convene hydrogen safety workshops to communicate research findings and disseminate information to safety stakeholders.
8 Conduct research as needed to fill data gaps on hydrogen properties and behaviors.
9 Conduct workshop to identify key performance parameters for hydrogen sensors and leak detection devices.
10 Assemble panel of experts in hydrogen safety to provide expert technical guidance to funded projects.
11 Identify user needs for Safety database.
12 Publish Safety database.
13 Safety Review Panel to prepare draft of Best Management Practices Handbook.
14 Complete final peer-reviewed Handbook.
15 Kickoff meeting between HAMMER, DOE and national laboratory staff.
16 Consensus 5-Year Plan for HAMMER released.
17 First hydrogen safety class (non-prop) offered at HAMMER.
18 First hands-on training prop completed.
19 Develop guidelines for hydrogen safety planning and inclusion in procurements.
20 Publish guidelines for safety plans.
21 First DOE annual review incorporating new emphasis on safety.
22 Establish annual review criteria for safety.
23 Publish final annual review criteria for safety on DOE Web site.

Outputs

Sf1 Output to Education: Report of common accident scenarios.
Sf2 Output to Education: Updated report of common accident scenarios.
Sf3 Output to Production, Delivery, Storage and Technology Validation: Safety requirements and protocols for refueling.
Sf4 Output to Storage and Technology Validation: Safety requirements for on-board storage.
Sf5 Output to Production, Delivery, Storage and Technology Validation: Safety requirements and protocols for refueling.
Sf6 Output to Technology Validation and Systems Integration: Sensor meeting technical targets.
Sf7 Output to Technology Validation, Education and Systems Integration: Final peer reviewed Best Practices Handbook.

Inputs

V9 Input from Technology Validation: Submit final report on safety and O&M of three refueling stations.
E1 Input from Education: Published initial perceptions report.
E2 Input from Education: Interim perceptions report.
E3 Input from Education: Final perceptions report.